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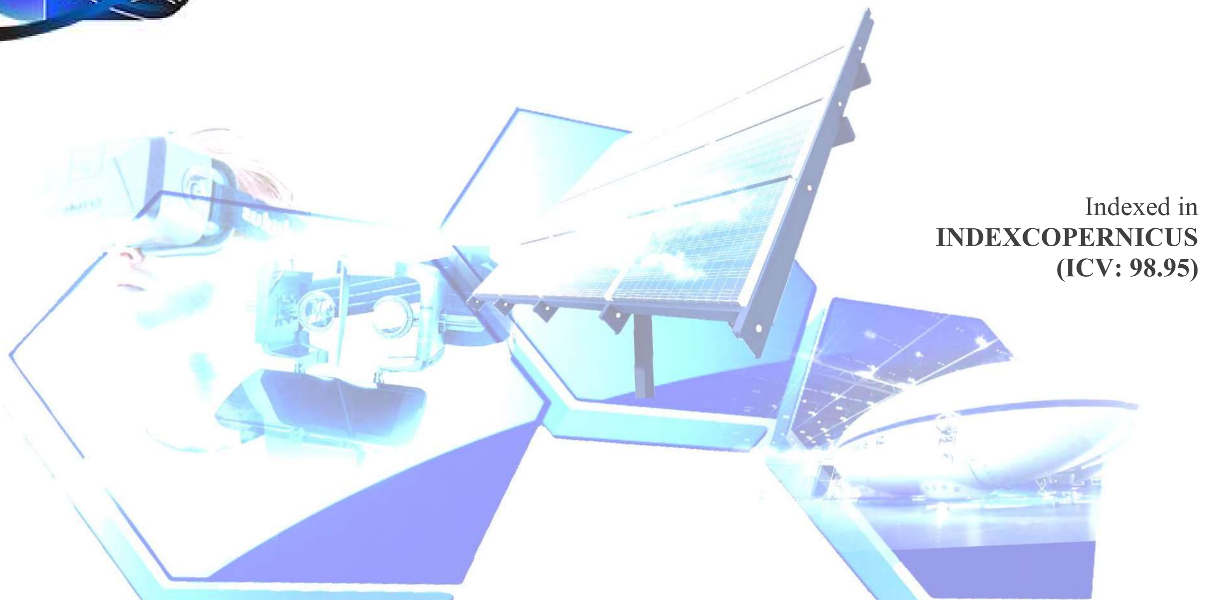

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ESTIMATION OF BUILDING INSULATION EFFICIENCY UNDER THE CONDITIONS OF CENTRALIZED HEAT SUPPLY WITH BRANCHED HEAT NETWORKS

ОЦІНКА ЕФЕКТИВНОСТІ УТЕПЛЕННЯ БУДИНКІВ В УМОВАХ ЦЕНТРАЛІЗОВАНОГО ТЕПЛОПОСТАЧАННЯ ПРИ РОЗГАЛУЖЕННИХ ТЕПЛОВИХ МЕРЕЖАХ СИСТЕМИ ТЕПЛОПОСТАЧАННЯ

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Abstract. *The paper considers the influence of building insulation on the thermal state of distribution pipelines of a centralized heating network for some characteristic laws of changing the flow rate of the heat carrying agent along the length of a heat pipe. Formulas are proposed for determining changes in heat losses by the supply pipelines of a multibranch network serving a group of buildings in the conditions of winterization. The formulas were obtained under the assumption that the heat pipe diameter varies along the length of the network not discretely from site to site, but monotonously from the maximum value at the beginning of the network to the minimum value at the connection to the system of the farthest consumer on a branch. The change in heat carrying agent flow rate along the length of network branches is also assumed to be monotonous. The formulas are obtained provided that the level of decrease in the calculated heating load of all buildings is the same. A comparison of the calculations results by the proposed formulas with the results of calculations obtained with the methods used in the practice of designing heating networks is performed. With a decrease in the design heating load due to building insulation by 60%, the maximum discrepancy in the results does not exceed 5%. The obtained formulas can be used in the development of algorithms for evaluating the effectiveness of alternatives upon thermal modernization of district heating systems.*

Keywords: *Centralized heat supply of a group of buildings · Building insulation · Heating system · Multibranch heat network · heat losses in pipelines of a heat supply network.*

Introduction

A feature of the existing heat supply systems in large cities of Ukraine is a high degree of centralization with the availability of a significant number of various heat sources and a complex system of main and distribution heat pipelines. It has now become apparent that despite the shortcomings of centralized heat supply systems, it is impossible to abandon them and move to other forms of organizing the production and distribution of thermal energy in a short time. This is due, first of all, to the need for significant investment in the reconstruction of the system. Therefore, most likely, the transition to heat supply from local heat sources will take place in stages, under the conditions of functioning of the reformed centralized systems. An element of the centralized heat supply systems of cities, where their problems are most concentrated, is the micro-district system. Distribution heat networks of a residential micro-district are characterized by branching and a large total length which significantly exceeds the length of the mains sections.

Most of the buildings that formed the development of micro-districts in Ukraine were commissioned from the middle to the end of the last century. The construction of buildings according to the normative requirements that existed at that time for the thermal resistance of external fences, which were significantly lower than the requirements in Western Europe [1, 2], caused the fact that the rate of thermal energy consumption per 1 m^2 of heated area in Ukraine exceeds several times the similar indicator in other countries with similar climatic conditions. Therefore, the main reserve of energy saving in the construction sector and municipal heating is to increase the thermal resistance of the elements in the building structures of buildings. For the buildings which are commissioned, this problem can be solved by applying an additional layer of thermal insulation to them. According to various estimates, provided that the actual heat transfer resistance of a building envelope of the commissioned buildings is enhanced up to the level of modern requirements, the heat loss by the building premises can be reduced by 20-40%. Under the conditions of centralized heat supply, when assessing the effectiveness of building insulation measures, it is also necessary to take into account the change in the thermal state of the pipelines of the heating network that supplies heat energy to the insulated buildings. This is explained as follows. It is most likely advisable to carry out a decrease in the supply of heat for heated premises of insulated buildings by decreasing the heat carrying agent temperature before supplying it to the heating system of the building. A decrease in the temperature of the heat carrying agent at the outlet of the heating system and a change in the system water flow for the operation of a heat exchanger lead to a change in the thermal and hydraulic modes of the distribution heat network operation. Reducing the water flow in the sections of the supply and return pipelines of the heat network contributes to more intensive cooling of water and a decrease in heat loss through thermal insulation. The decrease in heat losses in the network sections of the return pipe of the micro-district heating network is due to both a decrease in the heat carrying agent flow rate and a decrease in its temperature at the outlet of the building heating system.

The aim of the work is to obtain analytical dependencies that allow us to carry out preliminary estimates of changes in heat loss through the thermal insulation of the heating network pipelines, taking into account the possible installation of building insulation. It is assumed that all buildings connected to the considered branch of the heating network are insulated.

Literature review

Heat losses from a section of an insulated pipeline with length l_i into the environment are determined by the heat transfer equation [3], which, as applied to the pipelines of heating networks, is used in the form [4]

$$Q_i = \frac{t_m - t_s}{\sum R} \text{ L k}, \qquad (1)$$

where t_m - average heat carrying agent temperature in the section; $\sum R$ - sum of thermal resistances that determine the heat transfer process for a particular method of laying heat networks; k - coefficient accounting for heat loss by structural elements of the heat network (taken depending on the method of laying the heat pipes [5]).

When installing above ground, the ambient air temperature is taken in the capacity of ambient temperature t_s; with the use of underground laying methods, the soil temperature at the depth of the pipeline axis is taken.

With known specific heat losses q by a pipeline of the given diameter, the heat loss at the section can be calculated from the temperature difference of the heat carrying agent at the input to the section t_b and ambient temperature according to the formula

$$Q_i = q \cdot l_i \frac{t_b - t_s}{\Delta t} \text{ k}, \qquad (2)$$

where Δt - difference between temperatures of the heat carrying agent and the environment at which the specific heat loss through the insulation q are obtained.

Either permissible (normative), or actual losses determined, for example, during thermal tests of networks may be used in the capacity of value q. Using the heat carrying agent temperature at the inlet to the design pipeline section and its cooling within the section, the outlet temperature is determined from the heat balance equation (3); this temperature is the input value for the next calculation section, etc. up to the most distant section of the flow line on the network branch.

$$Q_i = \text{C} \cdot G_i \, (t_b - t_c), \qquad (3)$$

where C - the specific heat of the heat carrying agent; t_c - temperature at the outlet of the design pipeline section.

When determining heat losses by pipelines of the return line of the heating network, the calculation begins from the most remote on the branch of the object. The temperature at the end of the design pipeline section is found taking into account heat losses and mixing of the heat carrying agent flow in the main branch pipe and the heat carrying agent flow from the main pipeline branch. This calculation allows us to get the results with sufficient accuracy, but it is cumbersome and performed for a specific network configuration.

The actual law of heat carrying agent flow rate change along the heat network branch length has a stepwise profile. Within each of the design pipeline sections, the flow rate is constant; the flow rate changes abruptly when the heat carrying agent enters the next section (Fig. 1). A formula suitable for performing estimates of heat carrying agent cooling can be obtained under the assumption that the heat pipe diameter does not vary discretely from section to section, but monotonously from the maximum value at the beginning of the branch (for the supply line) to the minimum at the place where the most distant heat energy consumer is connected to the system. The change in heat carrying agent flow rate along the pipeline length is also assumed to be monotonous.

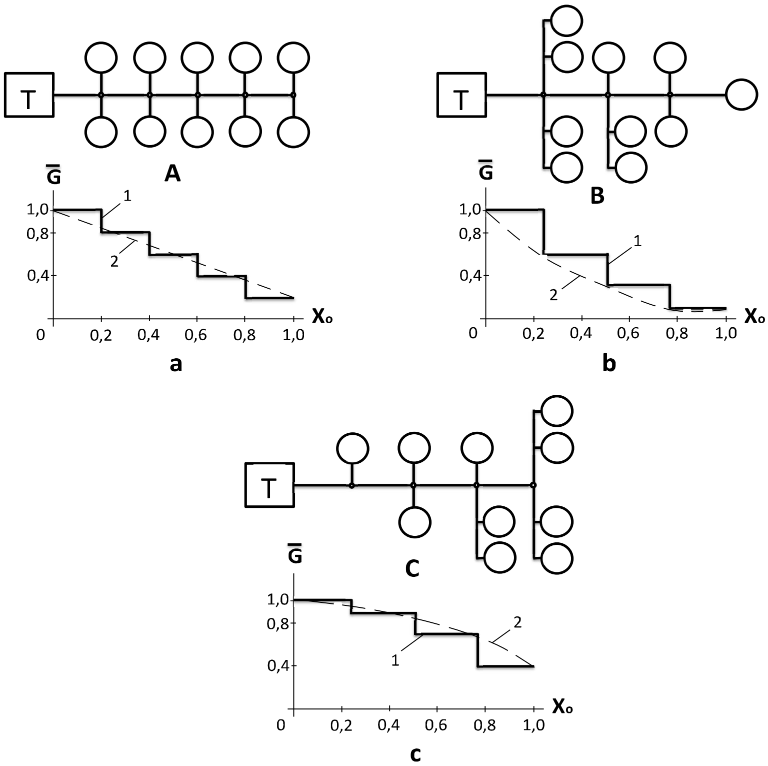

Fig. 1. Heating networks (A, B, C) design schemes and charts for heat carrying agent flow rate change along the length (a, b, c)

A - building; T - central heating station; 1 - the actual flow rate change law; 2 - the accepted law of consumption change.

In the work [6], the results of solving the differential equation describing the heat balance in an elementary section of a network supply pipeline are presented for specified conditions. The results of solving the differential equation for various laws of change in the heat carrying agent flow rate are given in table 1. In the proposed equations x_0 =x/L is a relative current coordinate value counted from the heat carrying agent inlet to the supply pipe, τ_1 is a heat carrying agent temperature at the branch inlet, i.e. at x_0=0, G_{max} is heat carrying agent flow rate at x_0=0.

Table 1

Rating dependencies for determining changes in flow rate and temperature of the heat carrying agent along the length of the heating network

Network variant (Figure 1)	The law of heat carrying agent flow rate change along the branch length	Heat carrying agent temperature change
A	$\bar{G} = 1 + ax_0$, (4) $\bar{G} = G(x_0)/G_{max}$	$t(x_0) = \tau_1 - A_1 \ln(1+ax_0)/a$, (7) $A_1 = qLk/(CG_{max})$
B	$\bar{G} = (1+bx_0^2)^{-1}$ (5)	$t(x_0) = \tau_1 - A_1 (\bar{x}+bx_0^3/3)$ (8)
C	$\bar{G} = (1 + cx_0)^{-1}$ (6)	$t(x_0) = \tau_1 - A_1 (\bar{x}+cx_0^2/2)$ (9)

The influence of measures to reduce heat loss through structural elements of buildings on the thermal state of pipelines of heating networks was considered, for example, in [7]. It is shown by the examples of heating networks calculations for groups of buildings, that when adjusting the heat carrying agent temperature at the input to the heating system of an insulated building, heat losses by pipelines of distribution networks are reduced by about 3-7%.

Research methodology

The building's heating complex performance after application of thermal insulation was determined provided that the heating system is connected according to an independent scheme [8] with the use of a heat exchanger. It is assumed that the hydraulic mode of the heating system of the building before and after the insulation is the same.

To find the water temperature in the heating appliances of an insulated building, the heat transfer equation of the heating device (10) and the balance ratio (11) are used.

$$Q_0 = K_o \cdot \Delta t_h \cdot F_o, \tag{10}$$

$$Q_0 = G \cdot C \cdot (\tau_3 - \tau_2), \tag{11}$$

where Q_0 - the heat flow transmitted from the system water to the indoor air; $\Delta t_h = 0{,}5(\tau_3+\tau_2) - t_L$ - the difference between the temperatures of the water in the heating device and the indoor air (t_L); τ_3, τ_2 - system water temperature at the inlet and outlet of the device, respectively; F_o - heat exchange area of the heater; G -water flow through the heater.

The heat transfer coefficient of the heater can be determined from the relation [5]

$$K_o = m \cdot (\Delta t_h)^{n_1} \bar{G}^{n_2}, \tag{12}$$

where m - constant factor depending on the design characteristics of the heating appliances; $\bar{G}$ - the relative consumption of system water through the device.

Exponents n_1 and n_2 are constant values for a specific type of heater. In further calculations, it is accepted that n_1= 0.2; n_2= 0.

The heater's thermal performance after insulating a building can be written as follows

$$Q_{0,N} = \mu Q_0 = K_{0,N} \cdot \mathrm{m}(\Delta t_h)^{0,2} = CG_N(\tau_{3,N} - \tau_{2,N}), \quad (13)$$

where $\mu = Q_{oN}/Q_o$ – coefficient which takes into account the effectiveness of the application of insulation measures; Q_o, Q_{oN} - heat consumption for heating the building before and after application of insulation measures, respectively (the "N" index in the above notation characterizes the "new" heat transfer conditions after warming).

As a result of transformations, taking into account relations (10) - (11), we obtain expressions for the supply water temperature at the inlet and outlet of the heating device, depending on the value of the building insulation efficiency coefficient μ

$$\tau_{3,N} = \tau_{2,N} + \mu \overline{Q_o} \theta_p, \quad (14)$$

$$\tau_{2,N} = (\tau_2 + 0,5\overline{Q_o}\theta_p - t_L)\mu^{0,8} - 0,5\,\mu \overline{Q_o}\theta_p + t_L, \quad (15)$$

where $\overline{Q_o} = (t_L - t)/(t_L - t_{p.o})$ - relative heating load; t is the current outdoor temperature value; $t_{p.o}$ - heating design temperature of outdoor air in a specific territory; $\theta_p = \tau_{3p} - \tau_{2p}$- design heat carrier cooling in the heating device before the building winterization; τ_{3p}, τ_{2p} - the heat carrying agent temperatures at the inlet and outlet of the building's heating device before the building winterization at the heating design temperature of outdoor air.

The accepted initial values (before winterization) of the system water temperature in the heating appliances at the design outdoor air temperature are $\tau_{3,p}$= 95^0C (at the input) and $\tau_{2,p}$= 70^0C (at the output). The values of the temperature of the system water in the heater for the specified initial data, depending on the coefficient μ values are given in table 2.

Table 2

The system water temperature in the heating device of the insulated building

Building insulation coefficient μ	1.0	0.9	0.8	0.7	0.6	0.5
Estimated system water temperature:						
heater input τ_{3p}	95	88.54	81.96	75.24	68.36	61.3
heater output τ_{2p}	70	66.04	61.96	57.74	53.36	48.8

The water flow from the distribution heat network for heating the heat-insulated building can be found from the heat balance equation (16) for the heat exchanger of the independent building heating system circuit. Heat balance is written for design outside air temperature

$$G_0 C[\tau_{S,p} - (\tau_{2,N,p} + \Delta\tau)] = G_{0,N} C(\tau_{3,N,p} - \tau_{2,N,p}), \quad (16)$$

where $G_{0,N}$ - water flow rate through the heating system of the heat-insulated building; G_0- water consumption from the heating network; $\tau_{S,p}$- water temperature in the supply pipe of the heating network at the entry to the building; $\tau_{3,N,p}$, $\tau_{2,N,p}$ - the heat carrying agent temperatures at the inlet and outlet of the heater in the heat insulated building at the heating design temperature of outdoor air; Δτ - the temperature difference between the heating system water at the outlet of the heat exchanger and the water temperature in the return pipe of the building heating system

Provided that the hydraulic mode of the building heating system does not change as a result of winterization, after the transformations we obtain the formula for the coefficient of water flow from external heating networks for heating the insulated building

$$\beta = \frac{G_S(\mu)}{G_S(\mu=1)} = \frac{\mu[\tau_{1,,p} - (\tau_{3p} + \Delta\tau)]}{\tau_{1,N} - (\tau_{2,N} + \Delta\tau)}, \quad (17)$$

where $\tau_{1,,p}$ - the temperature of the heat carrying agent in the supply pipe of the heating network at the heating design temperature of the outside air; $\tau_{1,N}$ - the design temperature of the system water in the supply pipe at the input to the heating system of the heat-insulated building; $\tau_{2,N}$ - the temperature at the outlet of the heater of the insulated building at the current outdoor air temperature

The change in heat loss from the heating network pipelines after winterization of the buildings connected to it can be estimated by the formula

$$\frac{Q'}{Q} = \frac{t'_{cp} - t_{окр.}}{t_{cp} - t_{окр.}} \quad (18)$$

The average temperature on a network branch can be calculated as the arithmetic mean of the values at the heat pipeline input $t(0)$ and output $t(1)$

$$t_{cp} = 0{,}5[t(0) + t(1)]. \quad (19)$$

To determine the temperature of the heat carrying agent at the corresponding points of the network pipeline we use formulas given in table 1.

Changing the flow rate of system water for heating an insulated building will lead to a change in the value of the complex A_1 in equations (7) - (9). The ratio of the values of the specified complex for a network branch after winterization of buildings and before the winterization has the form

$$A'_1 = A_1/\beta. \quad (20)$$

The final formulas for evaluation of changes in heat losses from the pipelines of the heating network supply line after building winterization are given in Table 3.

Table 3

Dependencies for determining changes in heat loss from supply pipelines in the case of winterization of all buildings connected to a branch of a heat network

The consumption change law	Change in heat loss	Formula number
$\overline{G} = 1 + ax_0$	$\frac{Q'}{Q} = \frac{a}{a'} \cdot \frac{2a'(\tau_1' - t_5) - A_1 \ln(1+a')/\beta}{2a(\tau_1 - t_5) - A_1 \ln(1+a)/\beta}$	(21)
$\overline{G} = (1 + bx_0^2)^{-1}$	$\frac{Q'}{Q} = \frac{2(\tau_1' - t_5) - A_1(1+b'/3)/\beta}{2(\tau_1 - t_5) - A_1(1+b/3)/\beta}$	(22)
$\overline{G} = (1 + cx_0)^{-1}$	$\frac{Q'}{Q} = \frac{2(\tau_1' - t_5) - A_1(1+0{,}5c')/\beta}{2a(\tau_1 - t_5) - A_1(1+0{,}5c)/\beta}$	(23)

In formulas (21) - (23) τ_1, τ_1' are the temperature of the heat carrying agent at the output from the central heating point to the supply pipe of the microdistrict network before and after the buildings are heat-insulated, respectively. In the context of the practical implementation of measures to winterize the buildings of the microdistrict, the heating network of which includes several branches, it is possible that individual buildings are already insulated, and winterizing work in the remaining buildings is still on-going. In this case, the temperature at the output from the unified control centre for thermal and hydraulic regimes of the microdistrict, which is the central heating unit, will be the same at the input to all heating complexes of buildings and equal to the value required for heating buildings without heat insulation. With equal temperatures $\tau_1' = \tau_1$, the calculation formulas given in table 3 are simplified. In addition, when all buildings on the branch of the heating network are heat-insulated, the requirement on equality of coefficients $a' = a$, $b' = b$, $c' = c$ in equations (21) - (23) is satisfied. After completion of the winterization of all buildings in the microdistrict, it is possible to switch the heating system of the microdistrict to a new lower temperature schedule. In this case, the inequality $\tau_1' \neq \tau_1$ is satisfied.

Results

The calculation results according to the proposed formulas were compared with the results of the heat losses calculation according to formulas (2), (3), taking into account the actual flow distribution along the length of the branch and cooling of the system water in the sections of the heating network. The calculations were performed for idealized building groups shown in Fig. 1, consisting of buildings with the same maximum heat consumption for heating $Q = 0.25$ MW. The diameters of the network section pipelines were found proceeding from the heat loads of the corresponding sections in the hydraulic calculation, provided that the specific pressure loss due to friction is within $30 \leq R \leq 50$ Pa / m. The lengths of design sections for the individual network variant are the same. Their values are found from the condition of equality of the material characteristics of the network as a whole, which for all the considered variants was taken equal to $M = \sum_{i=1}^{n}(l_i d_i) = 113.2$ m^2 (l_i is the length of the section, d_i – diameter, n - the number of design sections). Specific heat losses through insulation are accepted at the level of normative values for Ukraine during underground installation of heat pipes in crawlways [6]. Heat losses by the structural elements of the heat network are taken into account by the coefficient k = 1.15 [7]. The calculations were carried out for the heating design temperature of outdoor air, which is for the climatic conditions of the city of Kharkov is -23 °C. The mains water temperature at the input to the heating network before winterization of buildings is assumed to be 105 °C. The system water temperature in the heating appliances at the design outdoor air temperature before the buildings were heat-insulated is τ_{3p}= 95°C (input to the heating system) and τ_{2p}= 70°C (output from the heating system). Characteristics of the variants considered are given in table 4. The calculations were performed for cases of building heat insulation without changing the heat supply temperature schedule $\tau_1' = \tau_1 = 105°C$ and insulation with adjustment of the temperature schedule $\tau_1' = 78.3°C$). The insulation efficiency coefficient for buildings is taken equal μ = 0.6.

Since the heat carrier flow rate for heating of the building and its cooling are interconnected, the heat pipelines thermal state calculation is performed iteratively, in a few approximations. Initially, the accepted distribution of the flow rate was adjusted taking into account changes in the system water flow rate for heating individual buildings; this change is a consequence of cooling water when moving through the network. As the calculations showed, in order to achieve sufficient accuracy for practical calculations, 2-3 iterations are necessary.

Table 4

Characteristics of the design variants for the heating network

Parameter	Network design variant		
	A	B	C
Maximum heat consumption for heating of a group of buildings, MW	2.5	2.5	2.5
Water consumption at the inlet to the supply pipe of the heating network, kg / s	23.9	23.9	23.9
The design network section length, m	136.6	180	150
Branch length, m	683	720	600
The average diameter of the branch pipeline, mm	166	157.2	189
The law of heat carrying agent flow change	$\bar{G}=1-0,8x_0$	$\bar{G}=(1+10x_0^2)^{-1}$	$\bar{G}=(1+x_0)^{-1}$
The average relative flow rate of the heat carrying agent on the branch before heat-insulating of buildings	0.6	0.46	0.7

The building insulation effect on the system water flow rate through a heat exchanger is shown in Fig. 2. It represents the results of calculations using the formula and taking into account the heat carrying agent cooling within each of the sections. As can be seen from Fig. 2, the provision of the necessary thermal performance of the heating system in insulated buildings at the same heat carrier temperature in the supply pipe of the heating network as it was before the winterization causes more than half decrease in water consumption from the heating network. The transition to a new, lower temperature schedule of the distribution heating network occurs almost at the same flow rate of the heating heat carrying agent through the heating heat exchanger as it was before the buildings were insulated.

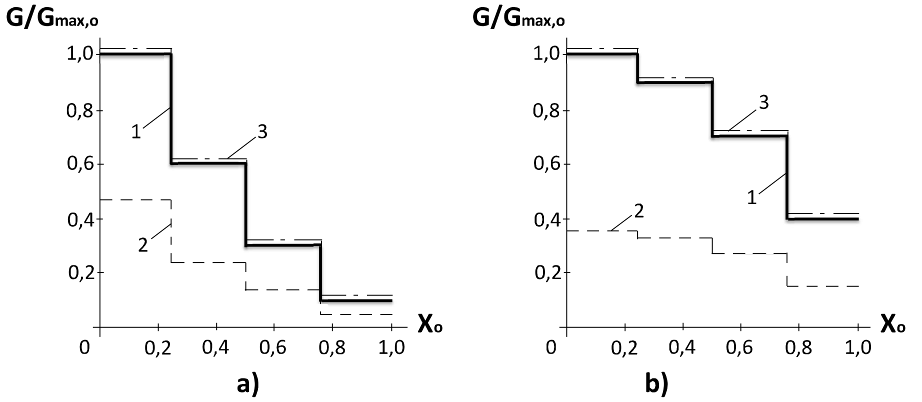

Fig. 2 - Change in the Relative System Water Flow Rate Along the Length of the Heating Network Branch;

a, b - design schemes B and C, respectively. 1- initial version (before insulation of buildings); 2 - $\mu = 0{,}6$; τ_1=105 °C; 3 - $\mu = 0.6$; τ_1=78.36 °C.

The results of calculations of the change in heat loss by the supply pipes of the heating network according to formulas (20) - (22) are given in Table 5. It also presents the results of calculating the thermal state using formulas (2), (3) and taking into account the actual changes in the flow rate and temperature of the heat carrying agent in the heat conduit sections. Comparison of the data obtained showed that with a maximum discrepancy of the results does not exceed 5%, which may be acceptable for estimates at the initial stages of the feasibility study of energy saving measures in micro-district heating systems.

Table 5

Reduction of heat losses from the supply pipes of the heating network in the case of building heat insulation

Terms of calculation	Method of determining	Values Q'/Q for the design scheme					
		A (Fig. 1)		B (fig. 1)		C (Fig. 1)	
		Q'/Q	Δ, %	Q'/Q	Δ, %	Q'/Q	Δ, %
μ=0,6 $\tau_1' = \tau_1$=105 °C	Calculation of cooling in sections, taking into account the actual change in flow	0.994	0.9	0.994	2,3	0.995	0.3
	Formulas (17) - (19)	0.985		0.971		0,991	
μ=0,6 τ_1' = 78,36 °C	Calculation of cooling in sections, taking into account the actual change in flow	0.734	0.4	0.734	4.6	0.734	0.3
	Formulas (17) - (19)	0.731		0.7		0.732	

Table 6

The ratio of heat losses from branches and total heat losses from heating network pipelines

Design scheme	Characteristics of variants		
	The original variant, before winterization (μ=1) τ_1=105 °C	insulation of all buildings connected to the branch (μ= 0.6) $\tau_1' = \tau_1$=105 °C	insulation of all buildings connected to the branch (μ= 0.6) τ_1' = 78,36 °C
A	Q_d/Q_{sum} = 0.18	Q_d/Q_{sum} = 0.18	Q_d/Q_{sum} = 0.18
B	Q_d/Q_{sum} = 0.20	Q_d/Q_{sum} = 0.20	Q_d/Q_{sum} = 0.20
C	Q_d/Q_{sum} = 0.22	Q_d/Q_{sum} = 0.22	Q_d/Q_{sum} = 0.22

The data given in Table 6 characterize the thermal state of the network without taking into account heat losses from branches laid from the main branch to the buildings. The impact of branch losses on the total heat loss in a network serving a group of buildings was assessed using formulas (2), (3) and taking into account the actual change in the heat carrying agent parameters in the sections. The calculations were performed provided that the material characteristics of the branches $M_d = \sum_{i=1}^{n}(l_i d_i)$ for all considered variants of the heating network are the same and equal to 17.8 m^2, which is 13.6% of the total material characteristics. According to the data given in Table 6, the share of heat losses from branch pipelines in the total losses from the heating network pipelines is 18-22%. Moreover, the value of the specified ratio of heat loss for a specific network configuration remains unchanged for all accepted variants of the functioning of the heating system.

Conclusions

1. Design formulas for a number of characteristic laws of changing the heat carrying agent flow rate along the length of a branch in a multibranch heat network are proposed to determine the change in heat loss from the supply pipelines of the heat network in a case if building insulation was installed.

2. Using the examples of idealized heating networks, it is shown that the proposed dependencies make it possible, with sufficient accuracy for engineering calculations, to evaluate the effect of building insulation efficiency on the thermal state of heating networks of centralized heat supply systems. With the effectiveness of building insulation μ = 0.6, the maximum discrepancy does not exceed 5 %.

3. Heat networks having a lower average heat carrier flow are characterized by lower heat losses from pipelines. The differences for the laws of heat carrying agent flow rate distribution along the length are about 2%, provided that the temperature schedule for regulating the heat supply for insulated buildings is the same as before the buildings were insulated and about 9% when adjusting the temperature schedule.

4. The calculation results indicate that the insulation of buildings practically does not affect the ratio of heat loss from branch pipelines to the total heat loss from the pipelines of the microdistrict heating network, which is approximately 18-22%.

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Анотація. *У роботі розглянуто вплив утеплення будівель на тепловий стан розподільних трубопроводів централізованої опалювальної мережі для деяких характерних законів зміни витрати теплоносія по довжині теплопроводу. Запропоновано залежності для визначення зміни теплових втрат подавальних трубопроводів розгалуженої мережі, яка обслуговує групу будинків, при утепленні будинків. Залежності отримані в припущенні, що діаметр теплопроводу змінюється по довжині мережі не дискретно від дільниці до дільниці, а монотонно від максимального значення на початку мережі до мінімального значення на вводі в систему найбільш віддаленого на гілці споживача. Зміна витрати теплоносія по довжині гілки мережі також при цьому передбачається монотонним. Залежності отримані за умови, що рівень зниження розрахункового опалювального навантаження всіх будівель однаковий. Виконано порівняння результатів розрахунків за запропонованими формулами з результатами розрахунків, отриманих з використанням методик, що застосовуються в практиці проектування теплових мереж. При зменшенні розрахункового опалювального навантаження за рахунок утеплення будинків на 60% максимальна розбіжність результатів не перевищує 5%. Виконано також оцінку зміни втрат теплоти трубопроводами мережі при застосуванні зниженого температурного графіка регулювання відпустку теплоти. Отримані залежності можуть бути використані при розробці алгоритмів оцінок ефективності варіантів термомодернізації систем централізованого теплопостачання.*

Ключові слова: *централізоване теплопостачання групи будинків, утеплення будинків, система опалення, розгалужена теплова мережа, теплові втрати трубопроводами теплової мережі.*

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